EFFECTS OF LANGMUIR CIRCULATIONS ON THE PLANKTON

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LONG TERM GOALS

My long term goal is to contribute to our understanding of the dynamics of marine populations and ocean-atmosphere interactions. Of particular interest to me are the effects of weather, and its climatic variation and long-term change, on the plankton and fish.

OBJECTIVES

I wish to establish whether the plankton is affected by Langmuir circulations (LCs). LCs are wind and wave induced flows in the mixed layer (ML) and comprised of counter-rotating, helical cells aligned with the wind. They occur broadly and frequently. While their surface manifestation is relatively well known, their dynamics and relation to the plankton are less well understood. Of particular interest is the effect of flow on plankton distributions and associated processes, including feeding, production, and mortality. The challenge is to measure plankton distributions and processes simultaneous with the physical flow and property distributions.

A specific objective for the past and present years' work has been to verify pattern of zooplankton-sized particles, observed with the profiling Optical Plankton Counter (OPC), by comparing them with results from plankton sampled by pump simultaneously. A further objective has been to attempt to quantify turbulence and heat flux.

APPROACH

I participated in the second FLIP cruise of the ONR Marine Boundary Layer (MBL) program, approximately 60 miles off Monterey, with marine meteorologists and physical oceanographers. My general approach was to sample the plankton and its environment continuously in the vertical, by profiling between the surface and base of the ML with a cycle time about 1-3 minutes, and at a single depth within the ML, at higher frequency. Measurements were made of temperature, salinity, and sigma-t (CTD), flow (Acoustic Doppler Velocimeter, ADV), chlorophyll *a* concentration (Chlorophyll Absorption Meter,

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CHLAM), and zooplankton concentration (plankton pump; collections; Optical Plankton Counter, OPC).

The approach for comparison of OPC and plankton pump samples has been to create single data sets for periods when both profiling and pump sampling occurred and analyze these statistically. Turbulence has been investigated from time series of u,v,w from the stationary ADV. Heat flux (w'T') has been investigated from time series of w from the ADV and T from the adjacent CTD, both stationary.

WORK COMPLETED

Our annual report last year summarized prior progress on this project. First, sampling was performed successfully and data obtained. Second, most data were processed to a first, largely-error-free level, with certain time periods having been examined in detail.

The past year we continued data analysis and completed zooplankton sample enumeration. We have yet to analyze fluorescence in the guts of copepods, the last remaining task in our sample analysis. Merged data sets from the profiling (OPC, CTD, CHLAM) and stationary instruments (CTD, ADV) and pump (zooplankton abundance from microscopic enumeration) have been created and are being analyzed.

The ADV and CTD data from periods of intense forcing and manifestation of LCs in the profiler temperature data [temperature = f(time, depth)] were analyzed to investigate turbulence and heat flux. This work is ongoing.

RESULTS

As stated in our prior year's report, LCs occurred and were quantified by our measurements. Conditions progressed from benign, with a stratified upper ocean, to strong winds and high waves, with well-developed LCs, followed by abatement. Forcing was quantified by estimating LC convergent velocity. LCs were manifest in the temperature distribution from our profiler data. We reported last year that LCs were further manifest in the skewness of the w component of velocity measured with the ADV. We feel now that this was likely an artifact of the ADV, something we only learned working with the manufacturer last year. The data, once corrected as feasible for this artifact, do not exhibit the skewness we saw originally. This does not preclude the existence of LCs, only their likely manifestation in our ADV w data.

Turbulence and heat flux estimates using ADV velocity data are likewise subject to artifact. We continue to work on this but, at present, are uncertain whether reliable estimates of these processes are feasible using our MBL ADV data.

Zooplankton was sampled by pump over two-minute intervals during ten time periods of 100 min each. All Formalin-preserved plankton has been enumerated. Small copepods (<~1.5mm cephalothoracic length) were numerically dominant, followed by small (<~0.8mm diameter) eggs, then *Metridia pacifica, Calanus pacificus, Eucalanus*

pacificus, and other taxa. Comparisons are underway between these data and those from our profiling OPC, in which zooplankton-sized particles show patchy distributions, particularly during periods with high forcing and apparent LCs, manifest in our temperature data. Preliminary results indicate reasonable correspondence which, in turn, indicates that the patterns of distribution and abundance of zooplankton-sized particles obtained with the profiling OPC are in fact for the zooplankton, our objecitve.

Statistical analysis of our profiling and stationary instrument data (e.g. temperature, particle concentration time series) has been performed using the Lomb periodogram and Lloyd's index of mean crowding. We will next use semi-variograms.

IMPACT

The means by which we have viewed the plankton and its physical environment in this study is novel and appropriate for future investigations. The patterns we have observed in the zooplankton during Langmuir circulations have not been seen previously. If accurate, these distributions are more heterogeneous than expected. This has implications for our understanding of pattern in acoustic backscatter, processes such as growth and mortality of the plankton, and the effects of the plankton on the biogeochemistry of the upper ocean. Most importantly, biological structure exists in the presence of strong wind and surface wave forcing.

TRANSITIONS

Our profiling instruments and software have been used in an ONR-funded study of a deep aggregation of copepods in the Santa Barbara Basin (with Kenric Osgood, SIO). We have also recently decided to use a modified OPC during standard CalCOFI sampling on station, based in part on the success of the work in this and the Santa Barbara Basin projects.

RELATED PROJECTS

The ONR-funded study of *Calanus pacificus* in the Santa Barbara Basin ended during the past year (Osgood and Checkley 1997, Osgood and Checkley in press). Checkley is funded by NOAA and Sea Grant to develop an automated fish egg sampling system, originally involving the OPC but presently based on real-time analysis of video (Checkley et al. 1997).

Other related projects follow. (1) Turbulence investigations with Tom Osborn (Johns Hopkins). (2) Heat flux (w'T') time series are being computed to compare with heat fluxes measured at the surface by Jim Edson (WHOI) and Carl Friehe (UC Irvine). (3) Zooplankton distributions and ADV-derived velocities are being compared with the backscatter and velocities measured by Rob Pinkel and Jerry Smith (SIO) with their upward-looking Deep 8 sonars.

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